Behaviour Of Steel Fibre Reinforced Concrete Beams With Duct Openings Strengthened By Steel Plates

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Abstract: In modern building construction, utility ducts and pipes are accommodated in the space above the false ceiling. Passing these ducts through openings in the floor beams eliminates a significant amount of dead space and results in a more compact and economical design. Including transverse openings in the web of a reinforced concrete beam induces high stress concentration at the corners of openings, reduces the beam stiffness and alters the simple beam behaviour to a more complex one. Therefore, in design, while providing large openings, the effects on ultimate and service load behaviour of the beam must be properly accounted for.

Steel fibre reinforced structural elements are widely used in the strengthening of reinforced concrete structures. Steel fibre composites offer excellent properties which are not available in the conventional construction materials. In addition, they have high strength-to-weight ratio and good fatigue properties. The ease of handling and application gives it an advantage over the traditional strengthening techniques, preventing the local cracks around openings and increasing the strength.

This paper discusses the use of steel fibres and steel plates to strengthen the opening region in reinforced concrete beams tested under two point loading. The test specimens of cross section 150x300mm and length 2000mm were used. The experimental programme included the testing of 14 reinforced concrete beams, two RC beams without opening (one without fibres and another strengthened with fibres), four RC beams with openings of different sizes in the shear zone, four steel fibre reinforced concrete beams with openings of different sizes in the shear zone and four steel fibre reinforced concrete beams with openings of different sizes in the shear zone strengthened with steel plates.

Solid beam without opening was considered as the control beam. The behaviour of reinforced concrete beams with and without openings at ultimate load, deflection and cracking patterns are investigated. The presence of duct openings in the shear zone reduces the load carrying capacity by 55 to 70 % for the beams with openings. Experimental results show that strengthening the duct openings with steel fibres increases the load carrying capacity and the ductility characteristics of the beam.

For Steel fibre reinforced concrete beams with openings of different sizes strengthened using steel plates, stiffening the duct openings with steel plates of 4mm thickness increases the load carrying capacity and there is a considerable increase in deflection of the beam before failure. Crack formation is delayed in the case of beam strengthened using steel plates.

Key Words: Beams with openings, Steel fibres, Duct openings, Steel Plates.

1. INTRODUCTION

It is necessary to provide duct openings in beams to accommodate the service pipes and service ducts in modern buildings as they play a vital role in high rise buildings. Sometimes the duct openings are used for aesthetical purpose also. Beam depth is one of the factors to decide the floor to floor height and overall height of the building.

The Structural Engineer faces a major problem in retaining the load carrying capacity of the beam without increasing the depth. If service ducts are provided at the bottom of the beam, then the floor to floor height increases and the overall height of the building also increases.

Provision of duct openings in beam reduces the load carrying capacity and stiffness of the beam. It results in formation of local cracks around the opening. Steel fibre reinforced structural elements are being widely used in the strengthening of reinforced concrete structures. The advantage of using steel fibres over the traditional strengthening techniques is the ease of handling and preventing the local cracks.

Saadatmanesh et.al (1992) investigated the behaviour of reinforced concrete beams strengthened with GFRP plates. The epoxy bonded GFRP plates on the tension face improved the flexural strength of reinforced concrete beams and cracking behaviour of the beams by delaying the formation of visible cracks. The crack widths are reduced at higher load levels.

Abdulla et al. (2003) proposed a design against cracking at openings in beams strengthened with fibre reinforced polymer and concluded that by using CFRP sheets, the deflection of the beam decreased. The formation of cracks was controlled around the opening and the load carrying capacity increased.

Mohammad et.al (2006) investigated the behaviour of reinforced concrete deep beams with web openings using finite element method. The numerical method of analysis developed was capable of providing useful information about the responses of reinforced concrete beams with web openings under monotonic load conditions.

Lee et al. (2010) investigated the R.C T-section deep beams strengthened externally with CFRP sheets and concluded that all shear compression failure due to partial elimination of CFRP sheets and U-wrapped anchorage CFRP sheets increased the load carrying capacity of the beam.

Pimanmas (2010) investigated the reinforced concrete beams with openings strengthened with externally installed FRP rods and concluded that placing of FRP rods partially was not effective but placing FRP rods in full length diagonally would be more effective in preventing the cracks.

Ammas et.al (2011) carried out the analysis of reinforced concrete beams with openings and beams strengthened by CFRP laminates and found that using fibre reinforced polymer offer significant advantages such as simplicity of installation, lower construction time and improved durability.

In this paper the results of an experimental programme conducted on reinforced concrete beams with and without duct openings of different sizes strengthened with steel fibres and steel plates to prevent local cracks are presented.

2. EXPERIMENTAL INVESTIGATION

In this experimental programme, tests were conducted on reinforced concrete beams with and without duct openings in the shear zone to determine the behaviour at ultimate load, deflection and the crack pattern.

2.1 Test Specimen Details

Totally 14 specimens were casted,

- Two RC beams without opening (one without fibres and another strengthened with fibres),
- Four RC beams with openings of different sizes in the shear zone,
- Four steel fibre reinforced concrete beams with openings of different sizes in the shear zone and
- Four steel fibre reinforced concrete beams with openings of different sizes in the shear zone strengthened with steel plates.

Solid beam without opening was considered as the control beam. All the beams had the same cross section and reinforcement. The typical details of the beams and the reinforcement are shown in Fig.1.

The test specimen of cross section 150x300 mm and length 2000 mm were used. Each beam had a longitudinal reinforcement of 3 numbers of 12mm dia. bars at the bottom, 2 numbers of 10 mm dia. bars at the top and 8mm dia. stirrups at 200 mm centre to centre spacing used as shear reinforcement.

The openings were of four different sizes, 150x150 mm, 150x200 mm, 150x250 mm and 150x300 mm. The width of the openings were varied keeping the same depth for all specimens.

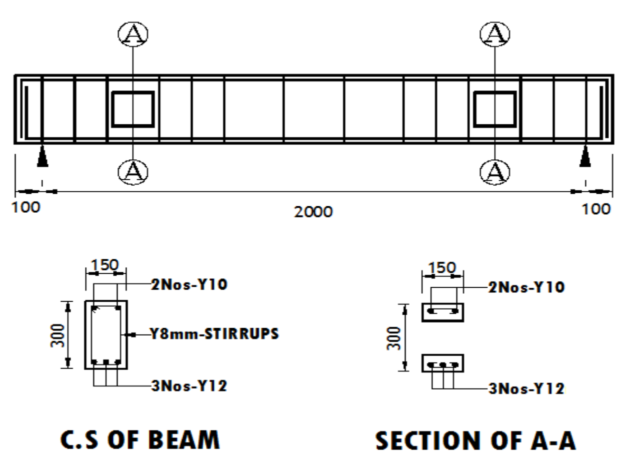


Fig. 1. Beam with Reinforcement Details

The details of the test specimens are shown in Table 1. The test specimens were made of M_{20} grade concrete and Fe 415 steel. Steel plates of 4mm thick were used for strengthening the opening region.

Table 1: Details of Beam Specimens

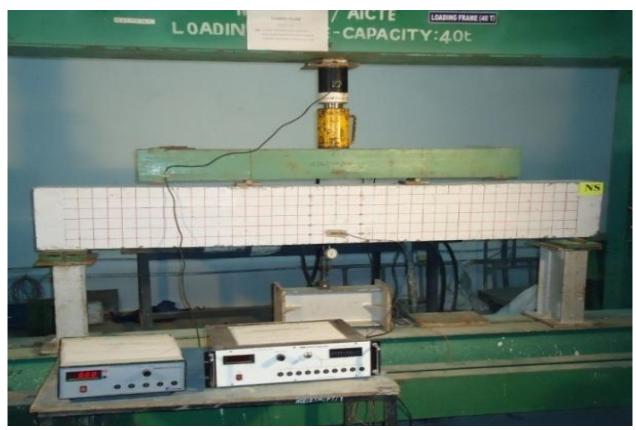
S.No.	Specimen Details	Opening size (mm)
1	NS	-
2	NSWF	-
3	NS150	150x150
4	FS150	150x150
5	CFS150	150x150
6	NS200	200x150
7	FS200	200x150
8	CFS200	200x150
9	NS250	250x150
10	FS250	250x150
11	CFS250	250x150
12	NS300	300x150
13	FS300	300x150
14	CFS300	300x150

The shear connectors were welded to the steel plates for proper bonding between concrete and steel plates. The details of the shear connectors used are shown in Fig.2. The nominal tensile strength of the steel plates is 250 N/mm^2. The steel plates were placed before concreting of the beam. The size of openings were kept large enough to cause sizeable reduction in the shear capacity.

Fig. 2. Steel Box with Shear Connectors.

2.2 Test Set-up.

The test set up consists of a loading frame of 400kN capacity with a hydraulic jack and strain indicator. The beams were simply supported and subjected to two concentrated static loads. Fig. 3 shows the test set-up. The openings in all the test beams were placed 100 mm away from the face of the support. Tests were carried out at a constant load increment of 5 kN upto failure. It was instrumented to measure the applied load and deflection at the mid span of the beam. The strain gauges were placed at the mid span and around the openings to measure the strains in the beams.



a) Control Beam

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b) Beam with Duct Opening

Fig. 3. Test Setup.

2. RESULTS AND DISCUSSION

The ultimate load, deflection, failure mode and load-deflection behaviour of control beam without opening, reinforced concrete beams with openings of different sizes, steel fibre reinforced concrete beams with openings and steel fibre reinforced concrete beams with openings strengthened using steel plates are observed.

Table 2 shows the ultimate load and deflection of the various beams tested.

Table 2: Ultimate Load and Deflection of Various Beams Tested.

S.No.	Specimen Details	Opening size (mm)	Load (kN)	Deflection (mm)
1	NS	-	145	8.8
2	NSWF	-	160	8.9
3	NS150	150x150	80	7
4	FS150		85	8
5	CFS150		125	12.8
6	NS200	200x150	65	7.2
7	FS200		75	7.4
8	CFS200		105	12.3
9	NS250	250x150	50	4.5
10	FS250		65	7
11	CFS250		95	11.4
12	NS300	300x150	40	4.1
13	FS300		55	6.9
14	CFS300		85	11

3.1 Load - Deflection Behaviour

The load-deflection behaviour of reinforced concrete beams with duct openings of various sizes of 150mm x 150mm (NS150), 200mm x 150mm (NS200), 250mm x 150mm (NS250), and 300mm x 150mm (NS300) is shown in Fig.4. Test results show that the presence of duct openings in the shear zone of reinforced concrete beams reduces the load carrying capacity by 45% to 70% and the deflection reduces from 20% to 55%.

The load carrying capacity decreases as the size of the duct opening increases. The deflection is less for the beam with duct opening when compared to the control beam due to immediate formation of wide cracks around the opening in addition to flexural cracks that propagated at the beam mid span. The formation of cracks is more when opening sizes increases.

The load-deflection behaviour of steel fibre reinforced concrete beams with duct openings of sizes 150mm x 150mm (FS150), 200mm x 150mm (FS200), 250mm x 150mm (FS250), and 300mm x 150mm (FS300) is shown in Fig.5.

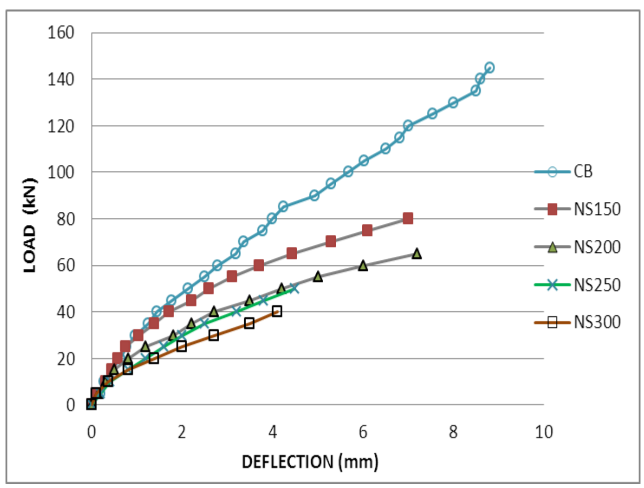

Fig. 4. Load - Deflection curve for RC Beams with Openings of Different Sizes.

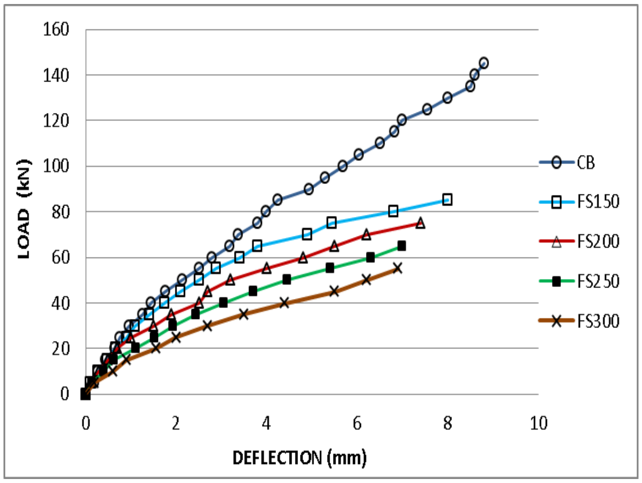

Fig. 5. Load - Deflection curve for Steel Fibre RC Beams with Openings of Different Sizes

From the load-deflection behaviour of steel fibre reinforced concrete beams with openings of different sizes, it can be seen that there is increase in the load carrying capacity and the deflection of the beam when steel fibres are used.

The load-deflection behaviour of steel fibre reinforced concrete beams with duct openings of sizes 150mm x 150mm (CFS150), 200mm x 150mm (CFS200), 250mm x 150mm (CFS250), 300mm x 150mm (CFS300) strengthened using 4 mm thick steel plates is shown in Fig.6.

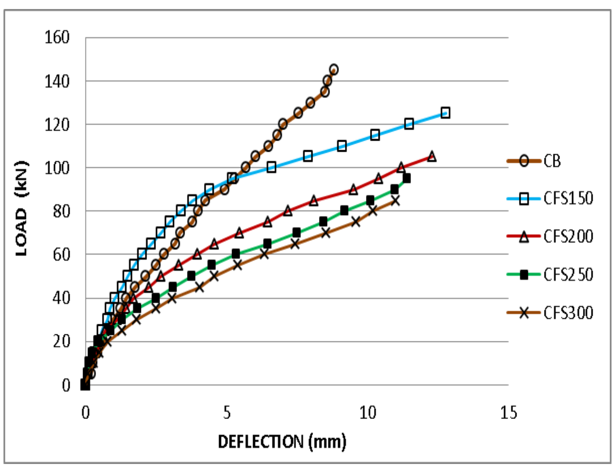

Fig. 6 Load-Deflection curve for Steel Fibre Reinf. Concrete Beams with Openings of Different Sizes Strengthened using Steel Plates

From the load-deflection behaviour of steel fibre reinforced concrete beams with openings of different sizes strengthened using steel plates, it can be seen that stiffening the duct openings with steel plates of 4mm thickness considerably increases the load carrying capacity and the ductility characteristics of the beam.

3.2 Effect of Strengthening the Beams with Duct Openings using Steel Fibres and Steel Plates

Fig.7. and Fig.8. show the comparison of ultimate loads and deflection of reinforced concrete beams with openings (NS150, NS200, NS250, NS300), steel fibre reinforced concrete beams with openings (FS150, FS200, FS250, FS300) and steel fibre reinforced concrete beams with openings strengthened using steel plates (CFS150, CFS200, CFS250, CFS300).

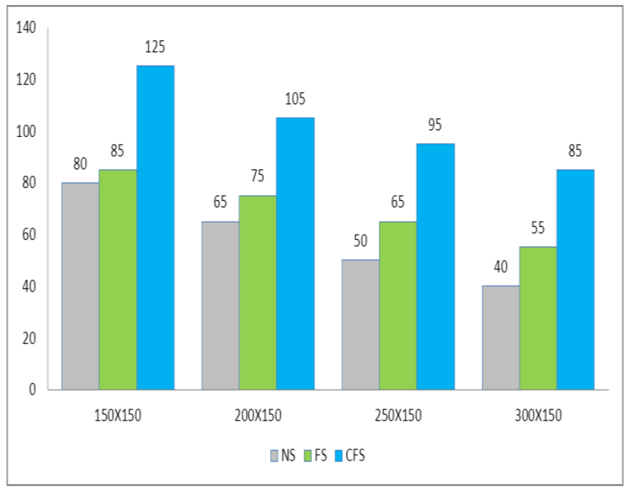

Fig. 7. Comparison of Ultimate Loads of Beams

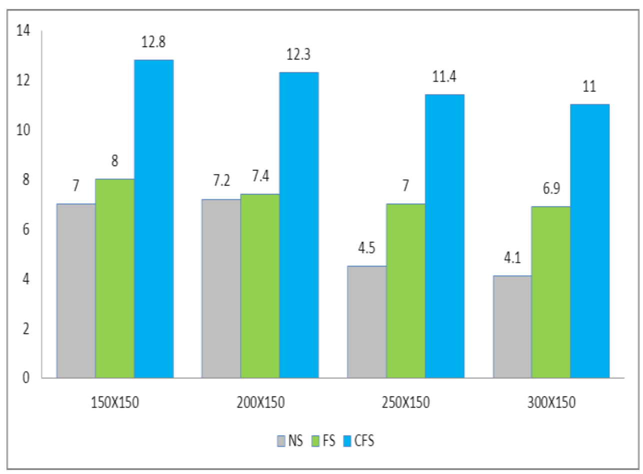

Fig. 8. Comparison of Deflection of Beams

It can be seen that using steel fibres in beams with openings increases the load carrying capacity in the range of 5 to 30%.

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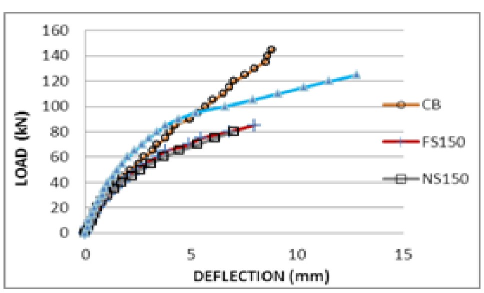
Steel fibres used in beams with openings increase the ductile characteristics of the beams considerably when the openings are of larger size.

Provision of smaller sizes of openings (150mm x150mm and 200mm x 150mm) decreases the ultimate load carrying capacity by 45% to 50% and deflection by 20%. If steel fibres are provided, then there is a marginal increase of ultimate load carrying capacity but the difference in the deflection is 15% for beams with square openings of size 150mm x150mm.

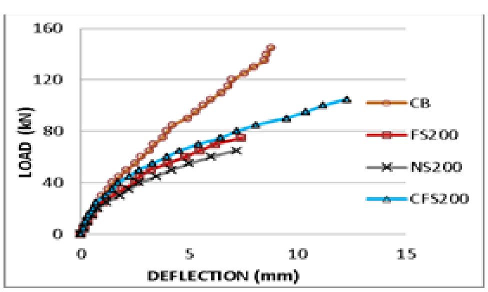
Providing larger size opening sizes (250mm x 150mm and 300mm x 150mm) decreases the ultimate load carrying capacity by 70% and deflection by 50%. If steel fibres are provided, then there is an increase of ultimate load carrying capacity by 30% and the deflection increases by 40%.

For steel fibre reinforced concrete beams with openings of different sizes strengthened using steel plates, stiffening the duct openings with steel plates increases the load carrying capacity and there is a considerable increase in deflection of the beam before failure.

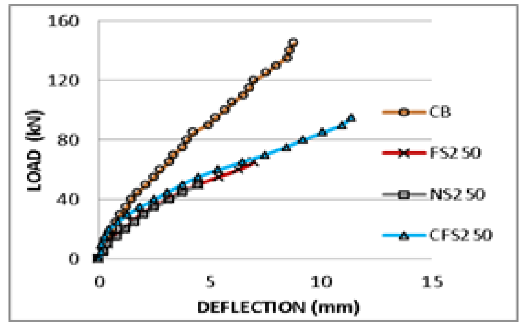
Fig. 9. shows the Load-deflection behaviour of reinforced concrete beams with openings (NS150, NS200, NS250, NS300), steel fibre reinforced concrete beams with openings (FS150, FS200, FS250, FS300) and steel fibre reinforced concrete beams with openings strengthened using steel plates (CFS150, CFS200, CFS250, CFS300).



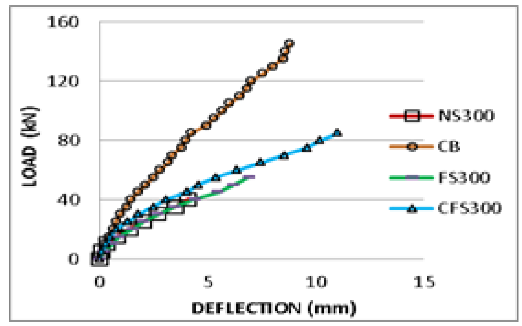
(a) 150mm x 150mm



(b) 200mm x 150mm



(c) 250mm x 150mm



(d) 300mm x 150mm

Fig. 9 Load-Deflection Curves of Control Beam, RC Beams with Openings, Steel Fibre Reinforced RC Beams and Steel Fibre Reinforced RC Beams Strengthened by Steel Plates for Different Sizes of Openings

In the case of beams with larger openings with and without steel fibres, initially the load deflection behaviour is almost the same. When steel fibre reinforced concrete beams with openings of different sizes are strengthened using steel plates, the ultimate load increases by 50% to 110%. The steel fibre reinforced concrete beams with openings of sizes 250x150mm and 300x150mm strengthened using steel plates(CFS250 and CFS300) are capable of deflecting more than two times with 65% increase in the load carrying capacity when compared to RC beams with openings(NS250 and NS300).

3.3 Failure Mode of Reinforced Concrete Beams with Openings Strengthened using Steel Fibres and Steel Plates

The mode of failure of these beams is typically due to shear failure at the opening region. The deflected reinforced concrete beam with openings is shown in Fig. 10.

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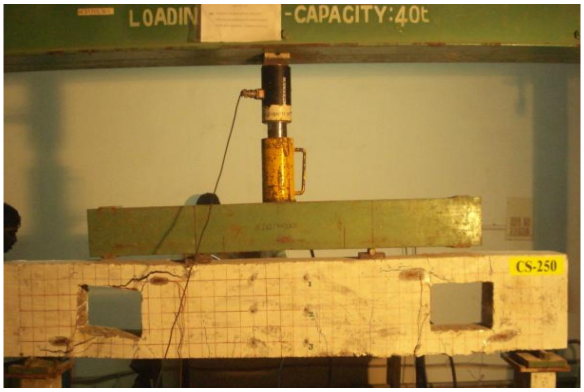
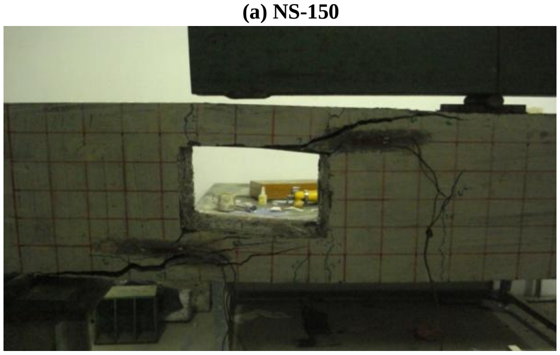


Fig. 10. The Deflected RC Beam with Opening

The first crack was observed at the bottom of the opening and at the side of the support for the beams without stiffened plates at about 20 KN. When the opening size increases, the deflection of beam at mid span decreases due to formation of cracks around the opening region.

Beams with openings of size 150 x 150mm (NS 150), 200 x 150mm (NS 200), 250 x 150mm (NS 250), 300 x 150mm (NS 300) without steel plates experienced wide cracks at the opening zone in addition to flexural cracks that propagated at the beam mid span. The formation of cracks is more when opening sizes increases. Fig.11. shows the crack patterns around the opening region for reinforced concrete beams with openings.

(a) NS-150

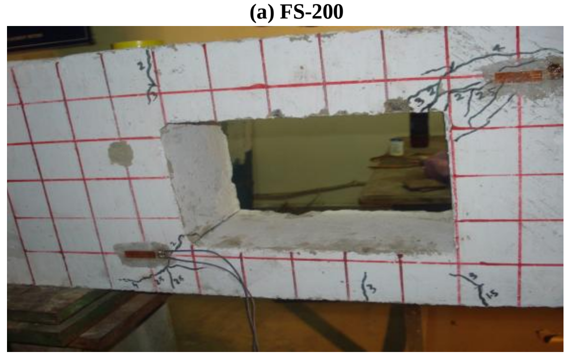


(b) NS- 200

Fig. 11. Failure Pattern of Beams with openings

Beams with openings of size 150 x 150mm (FS 150), 200 x 150mm (FS 200), 250 x 150mm (FS 250), 300 x 150mm (FS 300) with steel fibres experienced lesser number of cracks at the corners of the openings than the beams without steel fibres. In addition to this, flexural cracks appeared in the mid span. The crack pattern is shown in Fig.12.

(a) FS-200

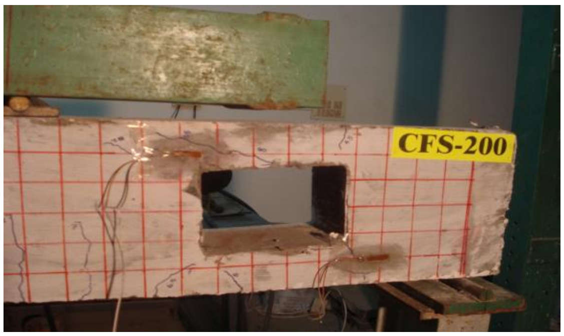


(b) FS-300

Fig. 12. Failure Pattern of Steel Fibre Reinforced Beams with openings

Crack formation was delayed in the case of steel fibre reinforced concrete beam strengthened using steel plates. The first crack was observed at the bottom of the opening and at the side of the support for the beams with stiffened plates at about 60 KN whereas in the case of openings not stiffened with plates, first crack was observed at 20 kN. Crack formation around the openings is delayed as the shear strength increases and the stress concentration of the openings is reduced by the steel plates. Figure 12 shows the failure pattern of beams strengthened with steel plates.

(a) CFS- 150



(b) CFS- 200

(c) CFS- 300

Fig. 12. Failure Pattern of Steel Fibre Reinforced Beams Strengthened with Steel plates

4. CONCLUSION

This paper discusses the results of tests conducted on 14 reinforced concrete beams, two RC beams without opening (one without fibres and another strengthened with fibres), four RC beams with openings of different sizes in the shear zone, four steel fibre reinforced concrete beams with openings of different sizes in the shear zone and four steel fibre reinforced concrete beams with openings of different sizes in the shear zone strengthened with steel plates. Solid beam without opening was considered as the control beam. Based on the experimental study, the following conclusions are made.

- The Presence of duct openings in the shear zone of reinforced concrete beams reduces the load carrying capacity by 45% to 70% and the deflection reduces from 20% to 55%. The load carrying capacity decreases as the size of the duct opening increases. The deflection is less for the beam with duct opening when compared to the control beam due to immediate formation of wide cracks around the opening in addition to flexural cracks that propagated at the beam mid span. The formation of cracks is more when opening sizes increases.
- Using steel fibres in beams with openings increases the load carrying capacity in the range of 5 to 30%. Steel fibres used in beams with openings increase the ductile characteristics of the beams considerably when the openings are of larger size. Beams with steel fibres experienced lesser number of cracks at the corners of the openings than the beams without steel fibres.
- For Steel fibre reinforced concrete beams with openings of different sizes strengthened using steel plates, stiffening the duct openings with steel plates of 4mm thickness increases the load carrying capacity and there is a considerable increase in deflection of the beam before failure. Crack formation around the openings is delayed as the shear strength increases and the stress concentration of the openings is reduced by the steel plates.

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